Earlier Springs in the Western US: Observations and Projections

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USGS

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CEC's
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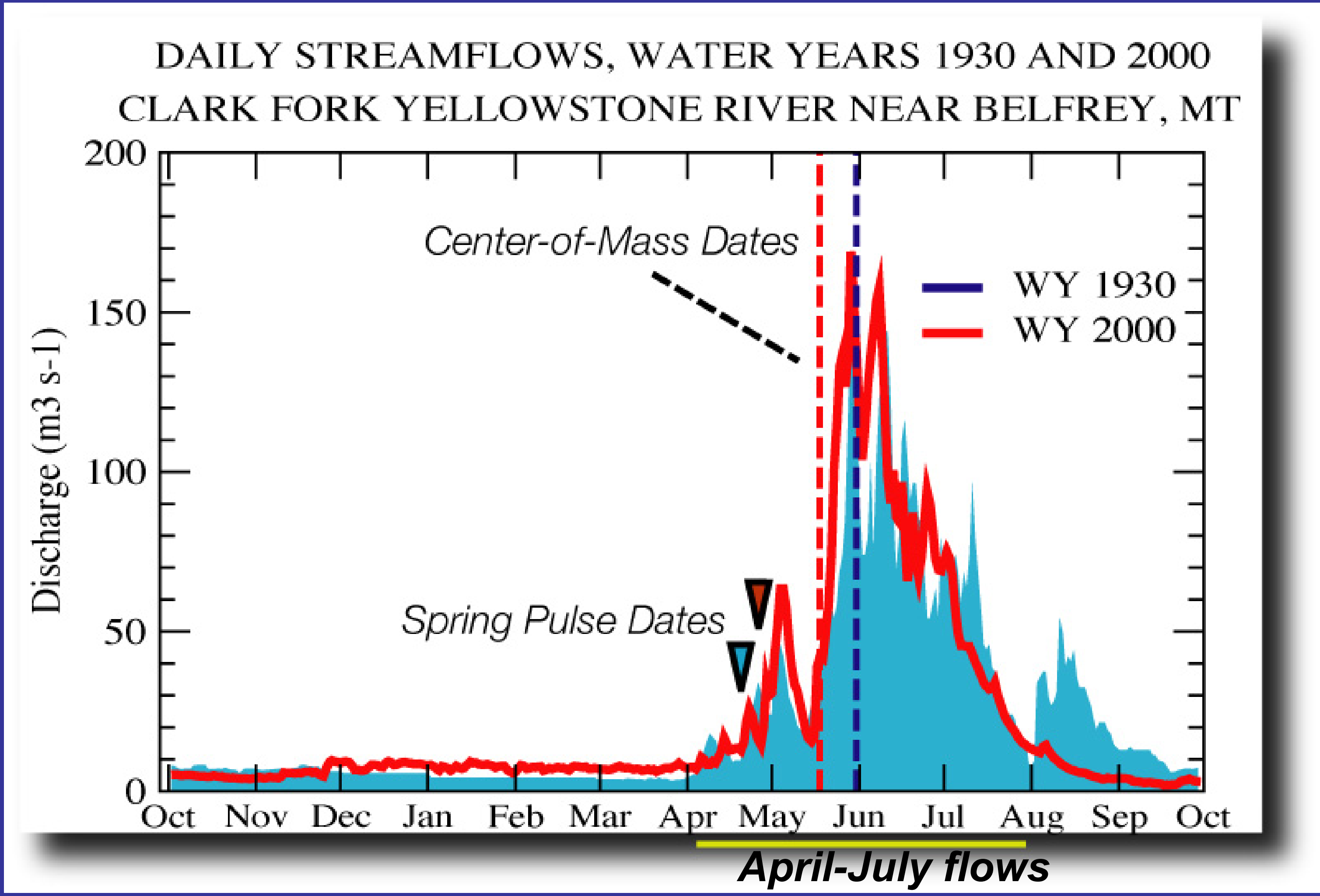
The timing of Western streamflow is important to water-resource management, *even where it is taken for granted*.

That timing can be monitored in terms of several measures.



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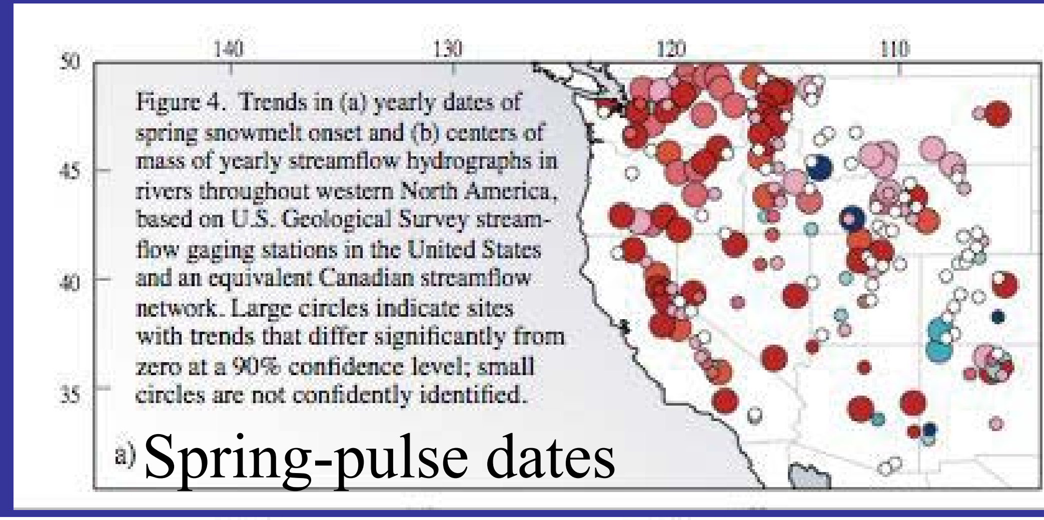
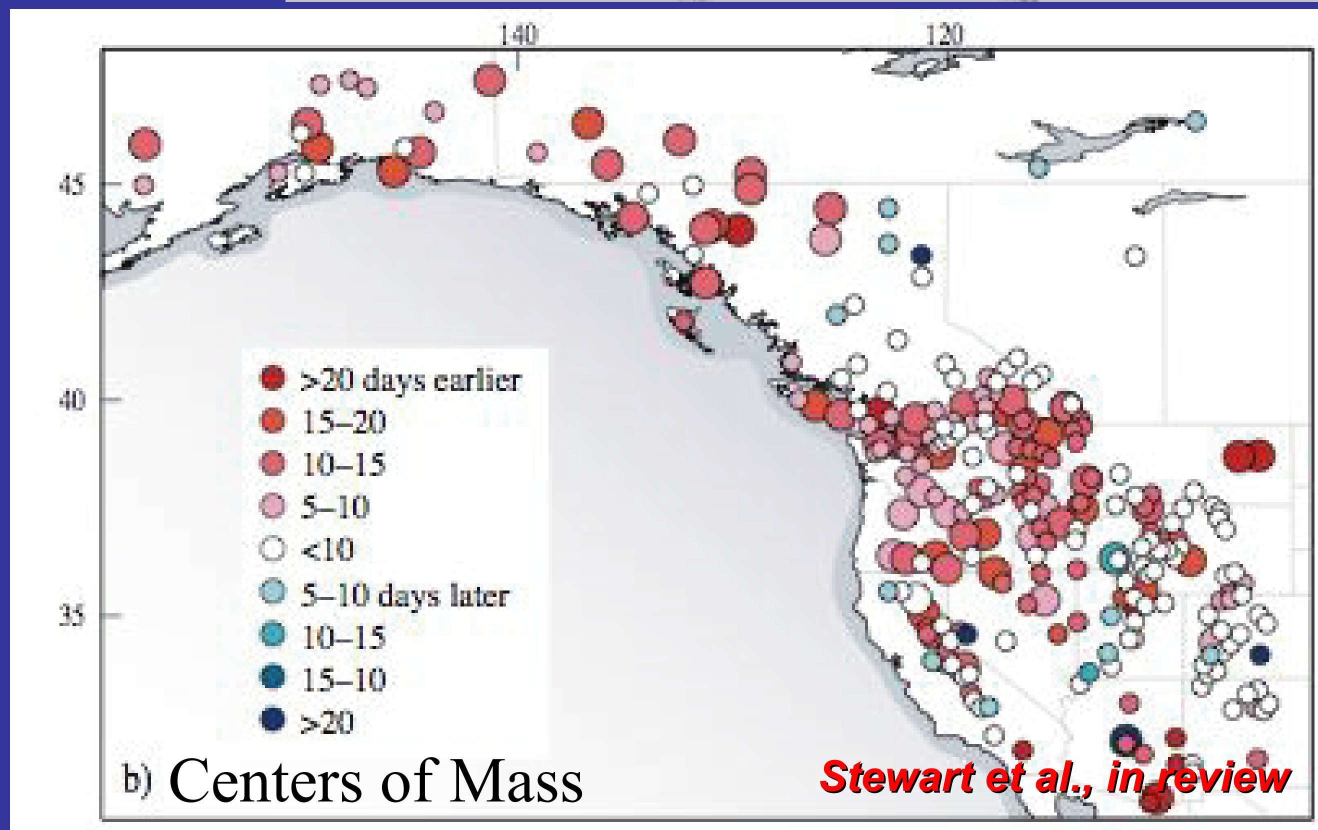
Western streamflow timing is largely set by our snowpacks, which hold most of the region's water supplies for weeks to months, until snowmelt begins.

In the Sierra Nevada:

- The average April 1 snowpack contains about 20 million acre-feet of water.
- The major foothill reservoirs (Shasta, etc) can hold a total of about 20 million acre-feet.
- Reservoir storage set aside for flood control reaches a total of about 5 million acre-feet.

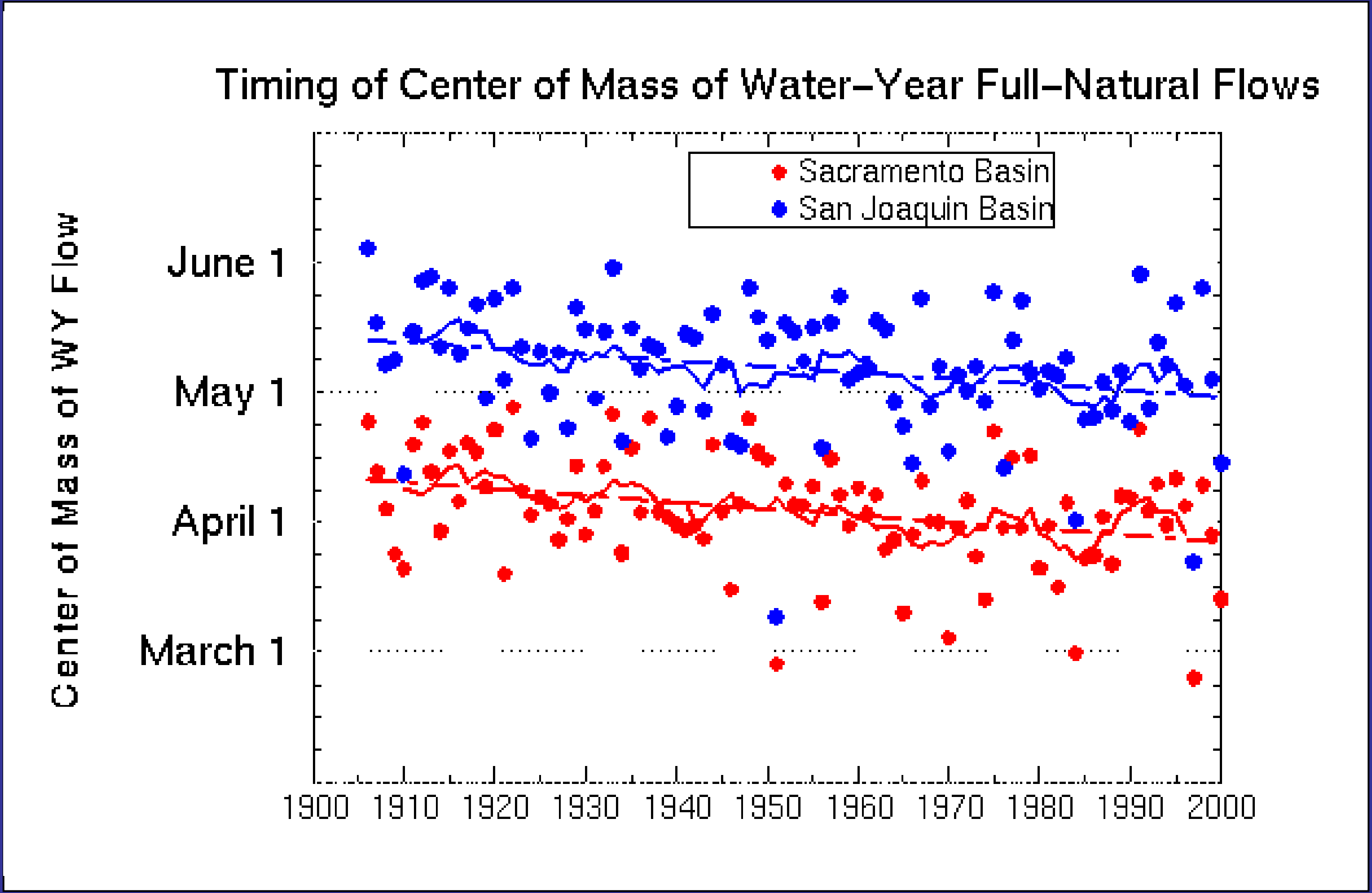
By several measures, Western streamflow has been arriving earlier in the year in recent decades.





Also: Dettinger and Cayan, 1995; Cayan et al., 2001

In California, this trend is widespread in the Sierra Nevada, and has yielded flows that are about 2 weeks earlier now.



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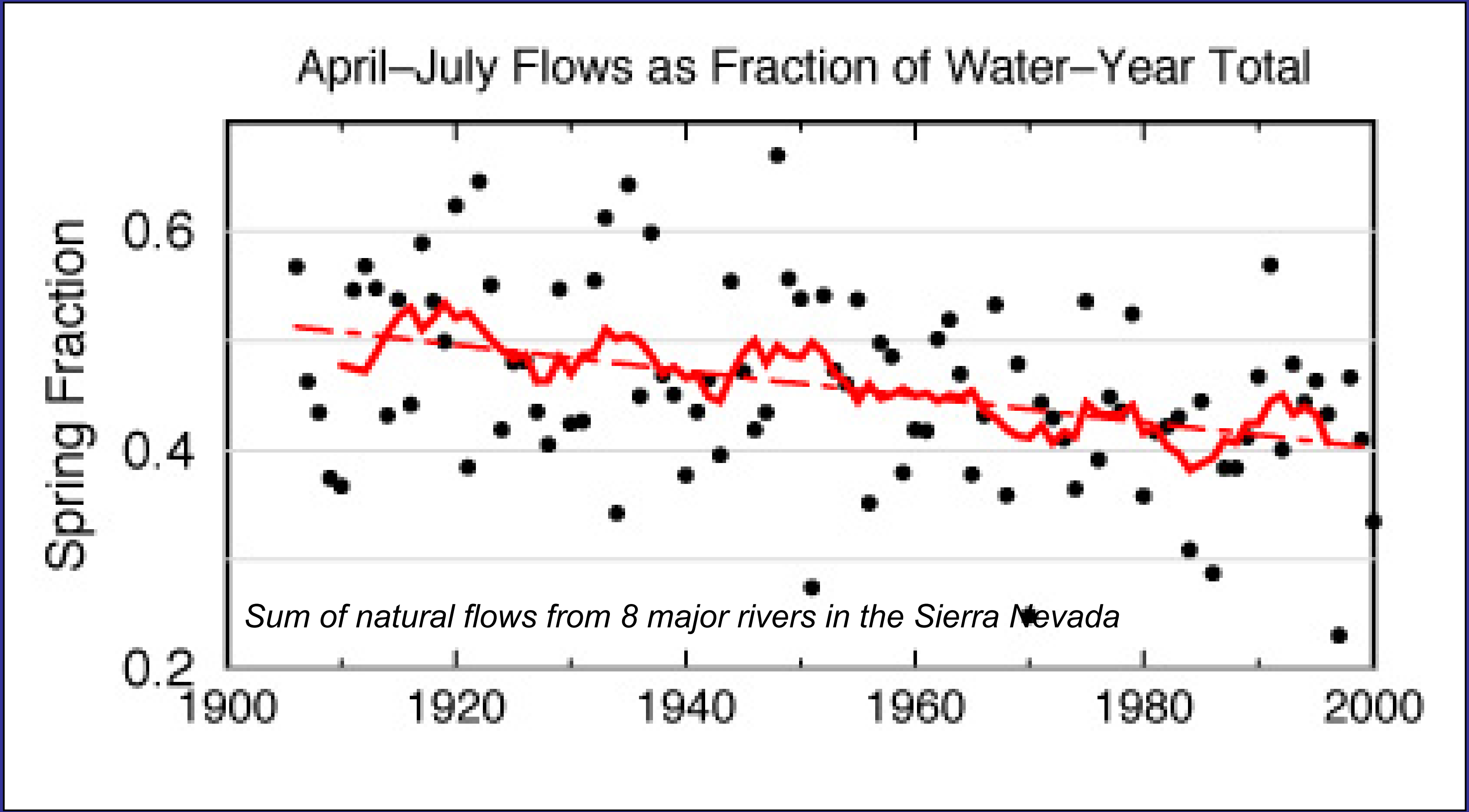
Roos, 1989, 1991; Dettinger and Cayan, 1995

As a consequence, the warm-season part of annual streamflows has been declining.



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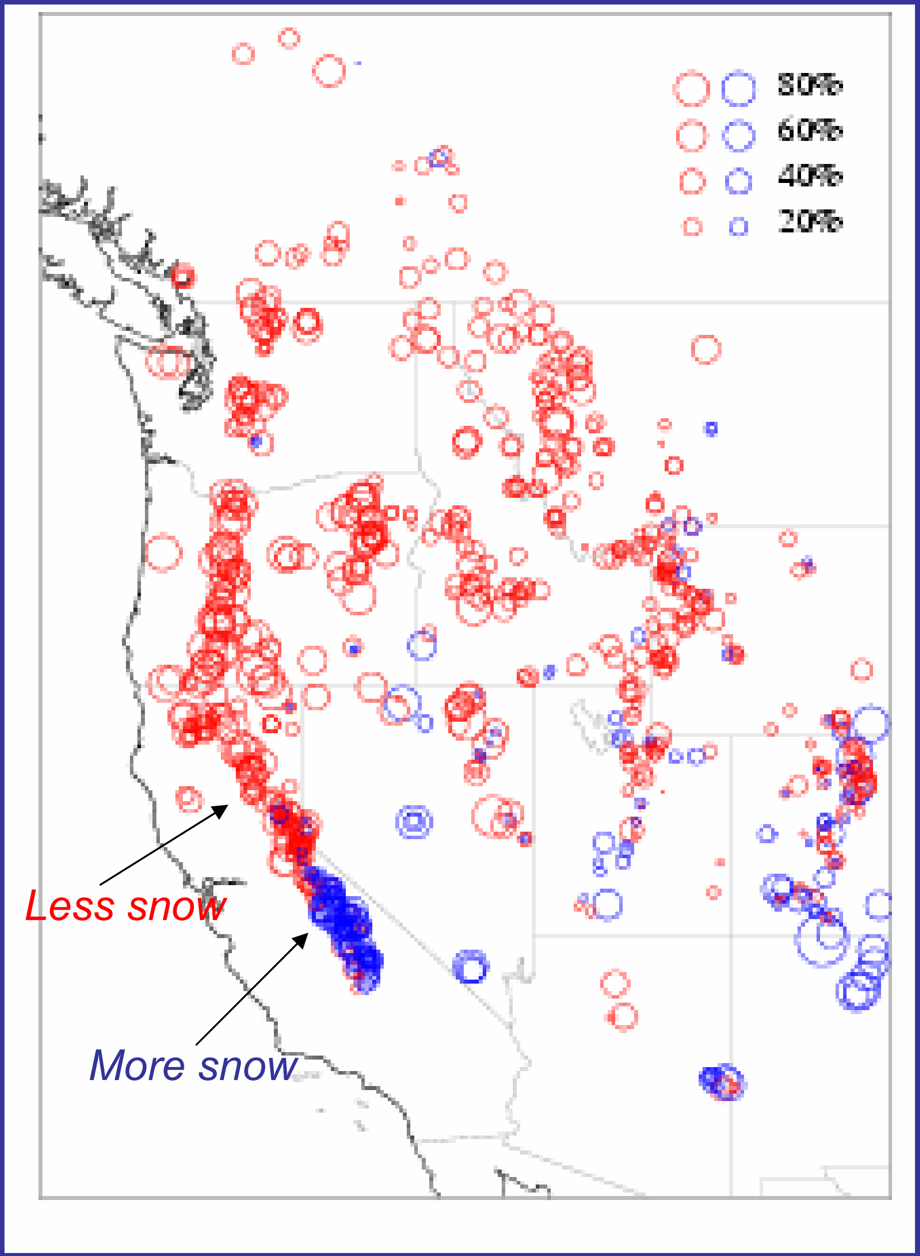
Dettinger and Cayan, 1995

These streamflow-timing trends reflect large-scale changes in snowpacks across much of the West, *especially at middle and lower elevations.*

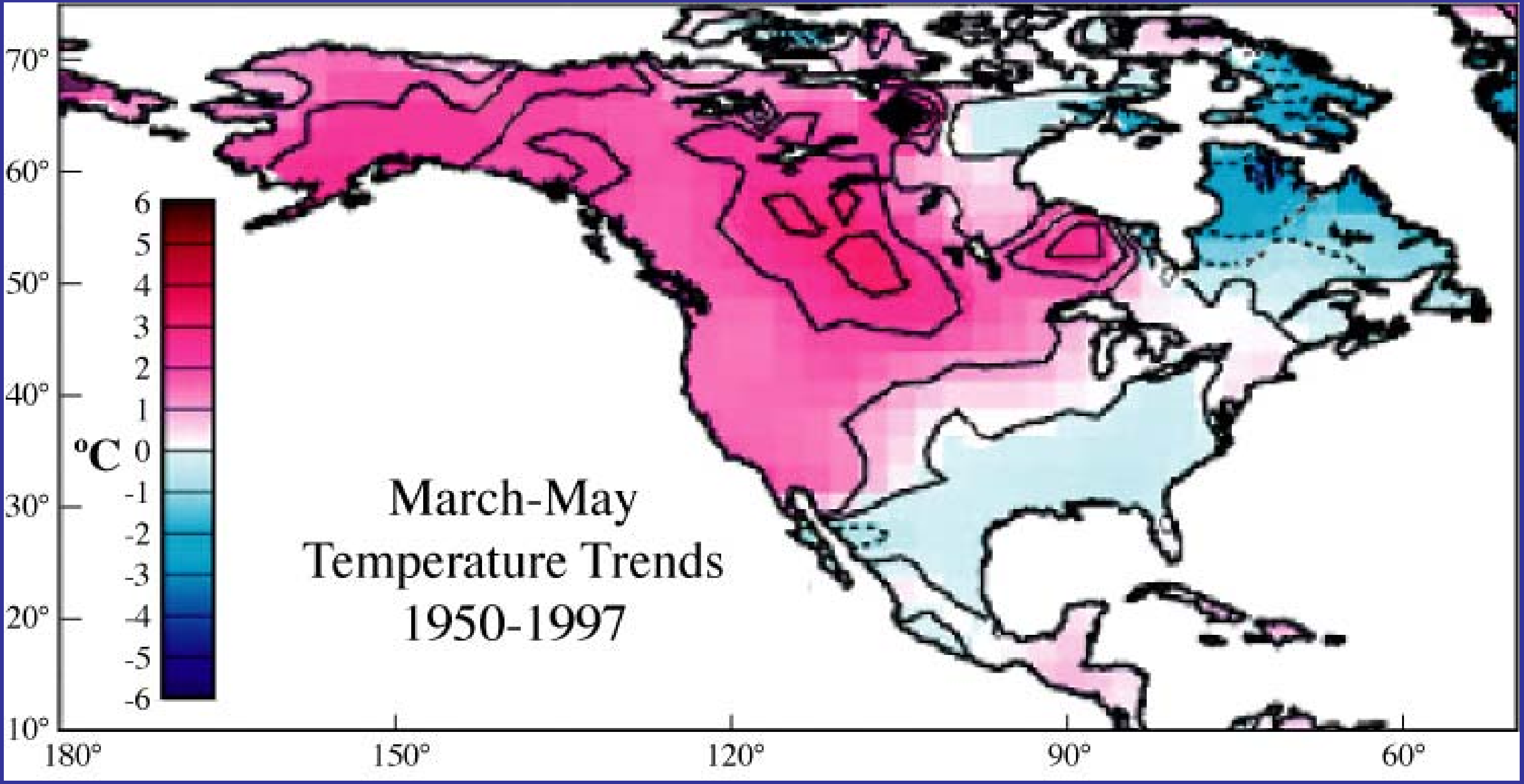
Snow is melting earlier over much of the region.

Linear trends (1950-97) in April 1 snow-water content at 824 western snow courses



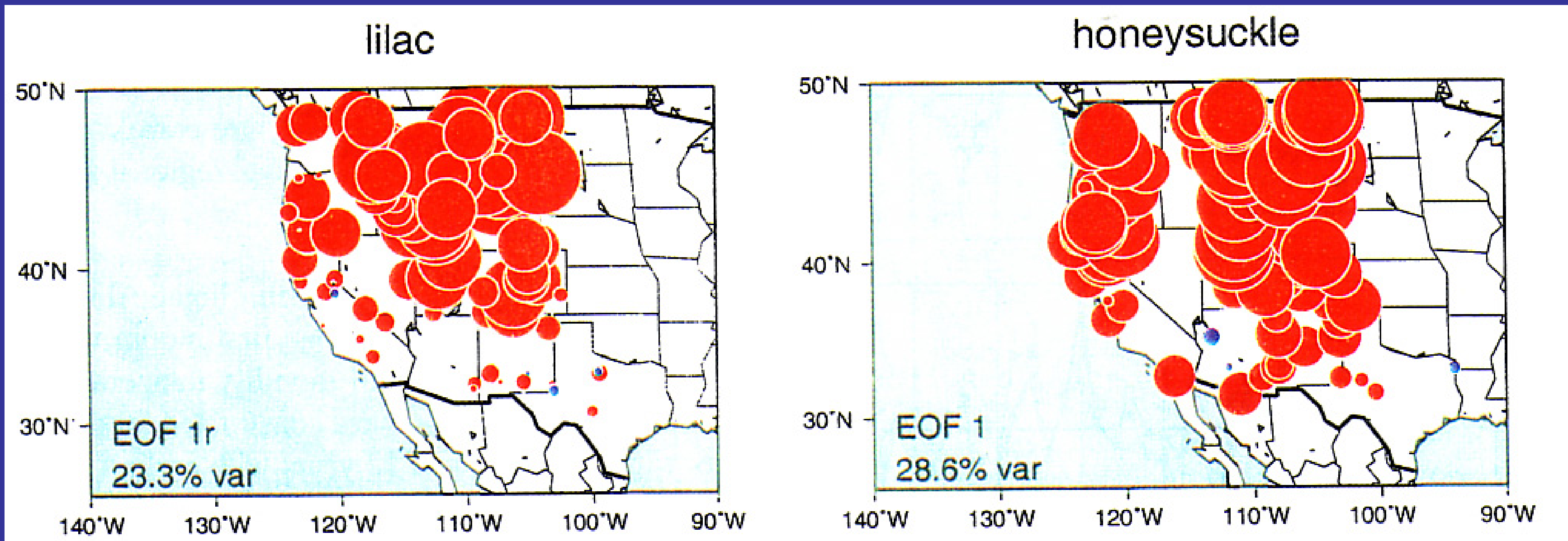
Philip Mote, 2003, GRL

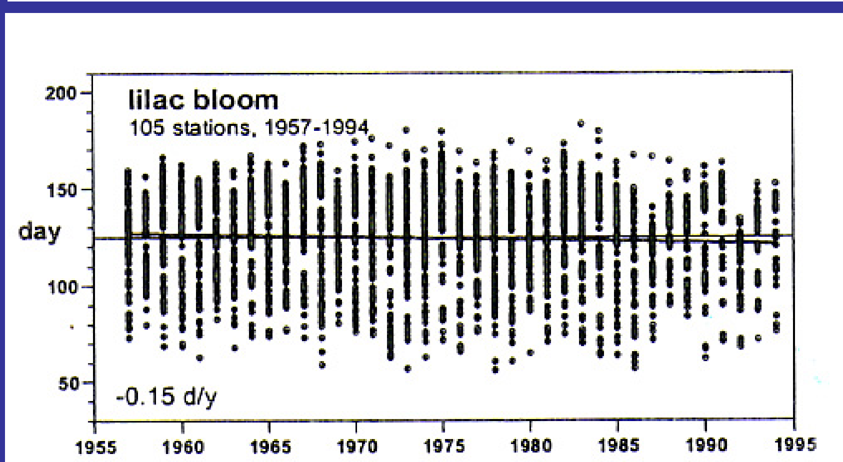
Not surprisingly, these timing and snowpack changes are attributable to long-term winter-spring warming trends across the West.

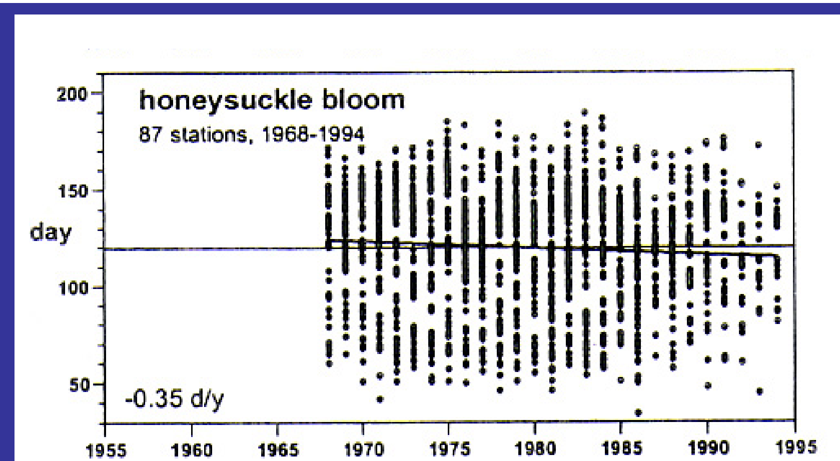


Cayan et al., 2001

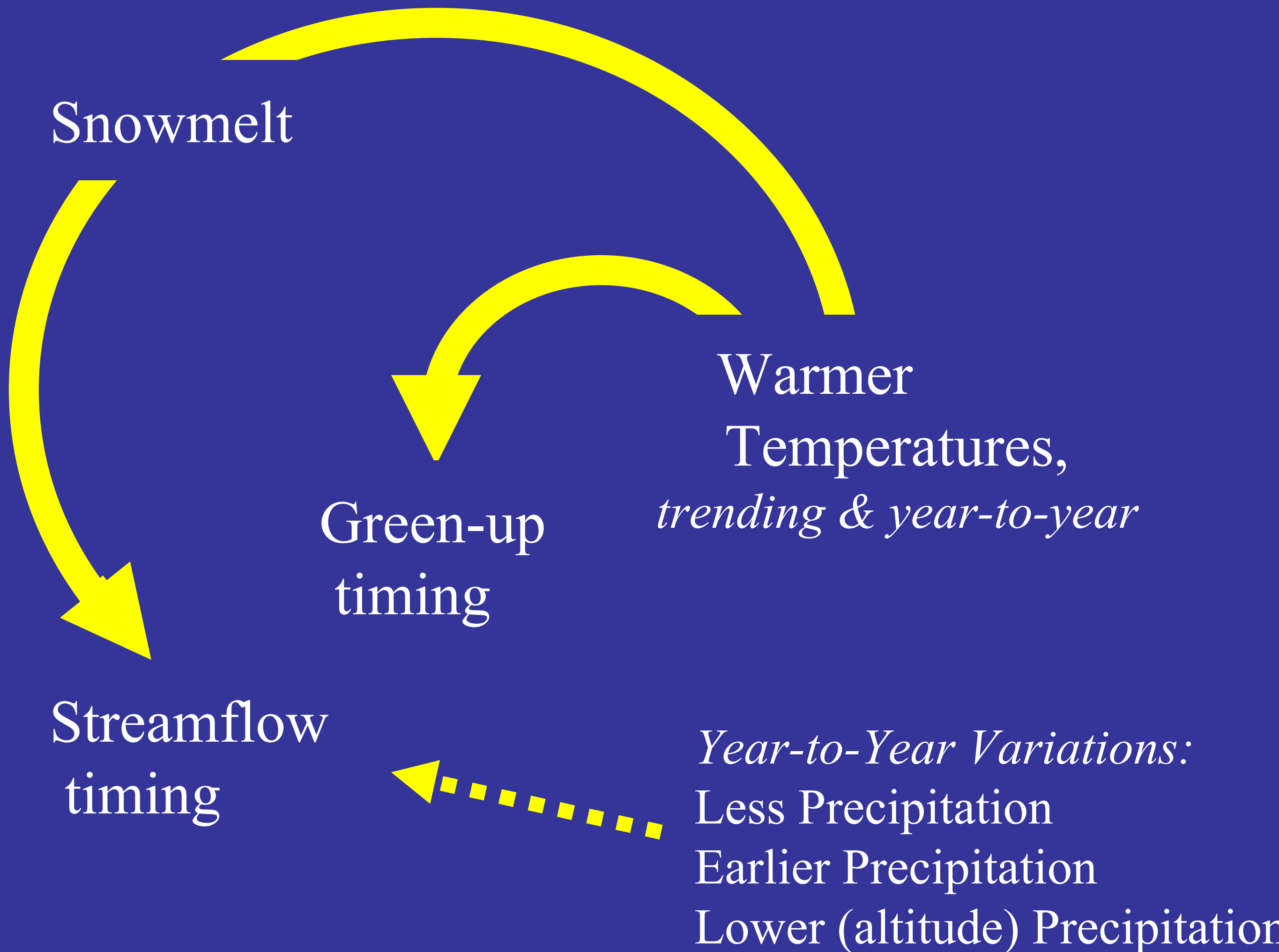
These trends are corroborated by corresponding changes in timing of spring "green up" across the West.







Cayan et al., 2001

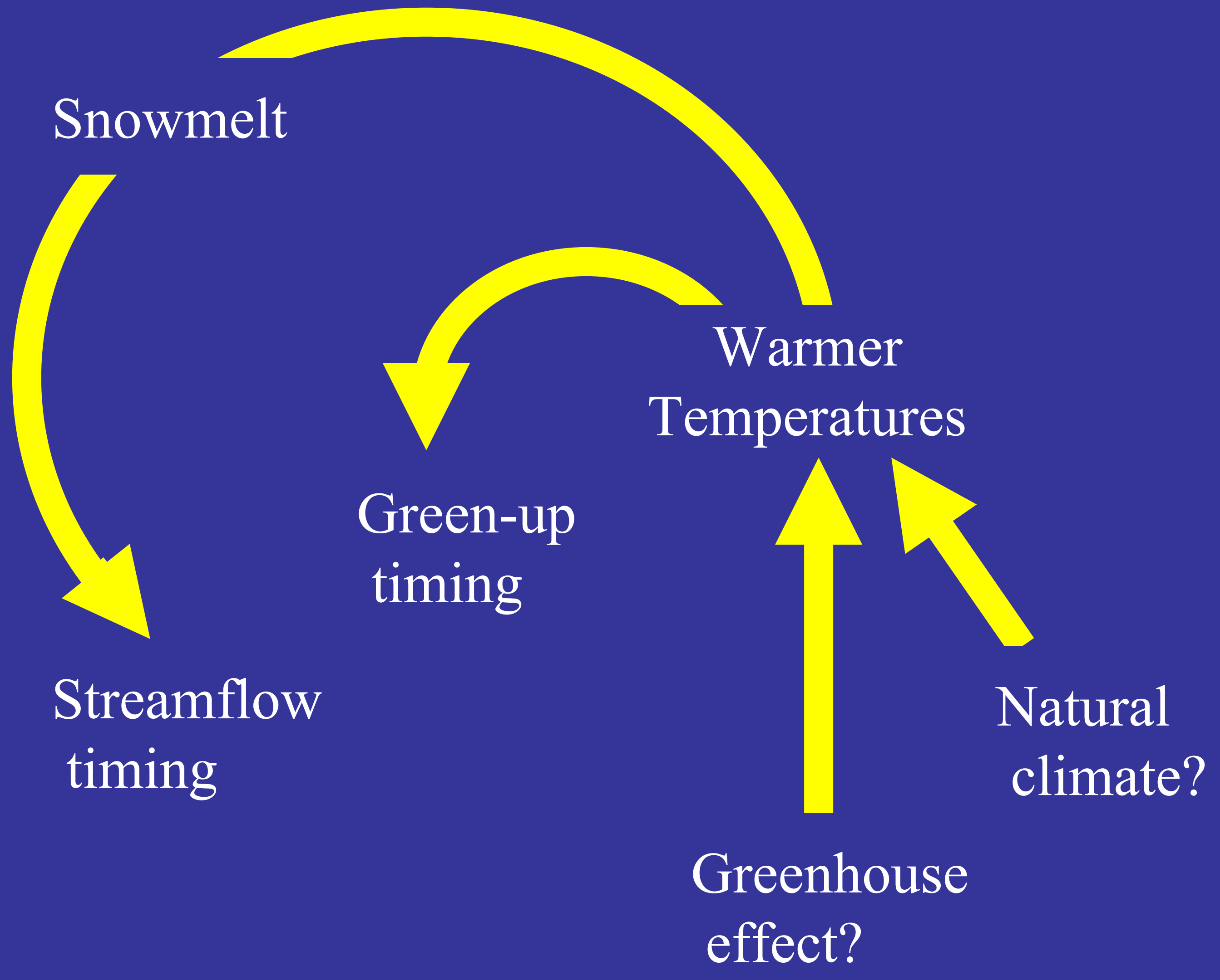

Snowmelt
Warmer Temperatures,
trending & year-to-year
Green-up timing
Streamflow timing
Year-to-Year Variations:
Less Precipitation
Earlier Precipitation
Lower (altitude) Precipitation

Snowmelt

Trending
Warmer
Temperatures

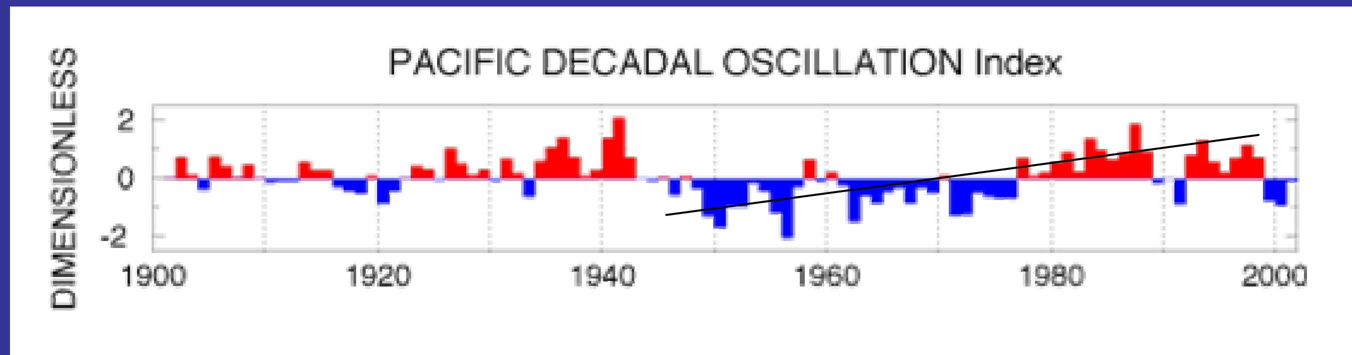
Green-up
timing trends

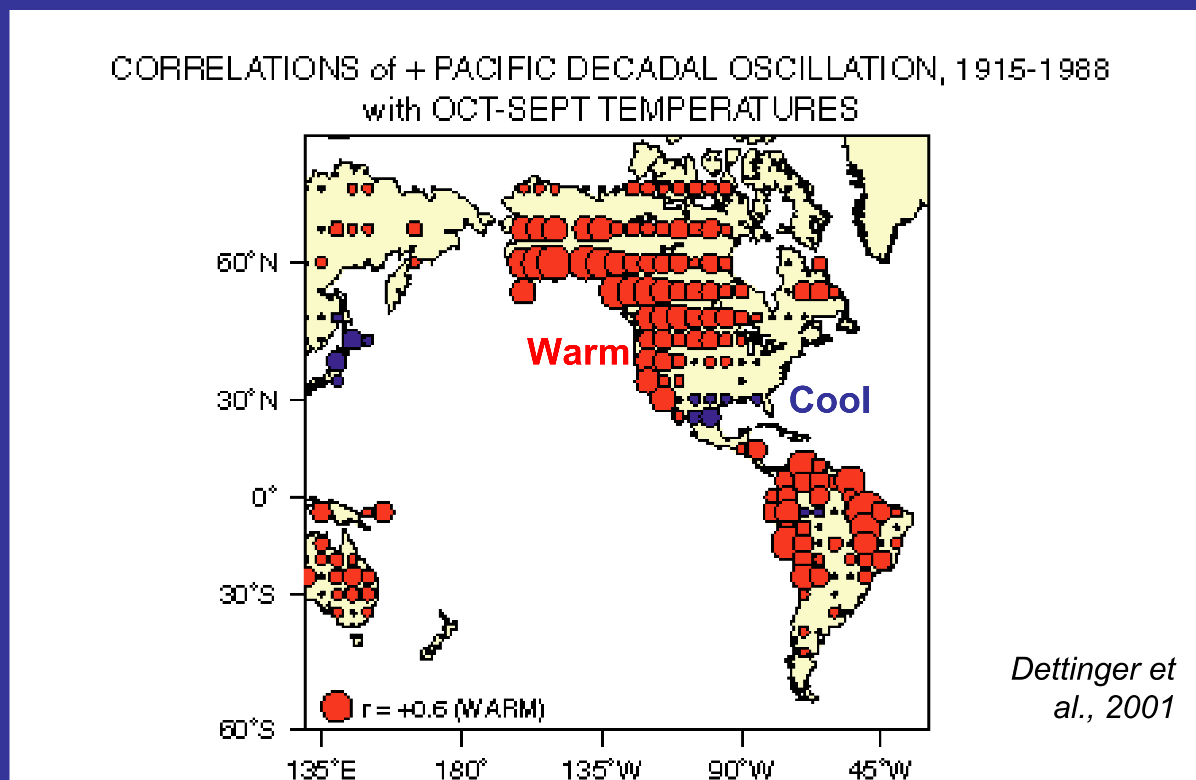
Streamflow
timing trends


Snowmelt
Warmer Temperatures
Green-up timing
Streamflow timing
Natural climate?
Greenhouse effect?

How much of the observed change is due to natural, decades-long fluctuations of the climate system?

The primary natural candidate to explain these trends is the multi-decadal Pacific Decadal Oscillation, *which makes the West warm in its "El Nino-like" phase.*

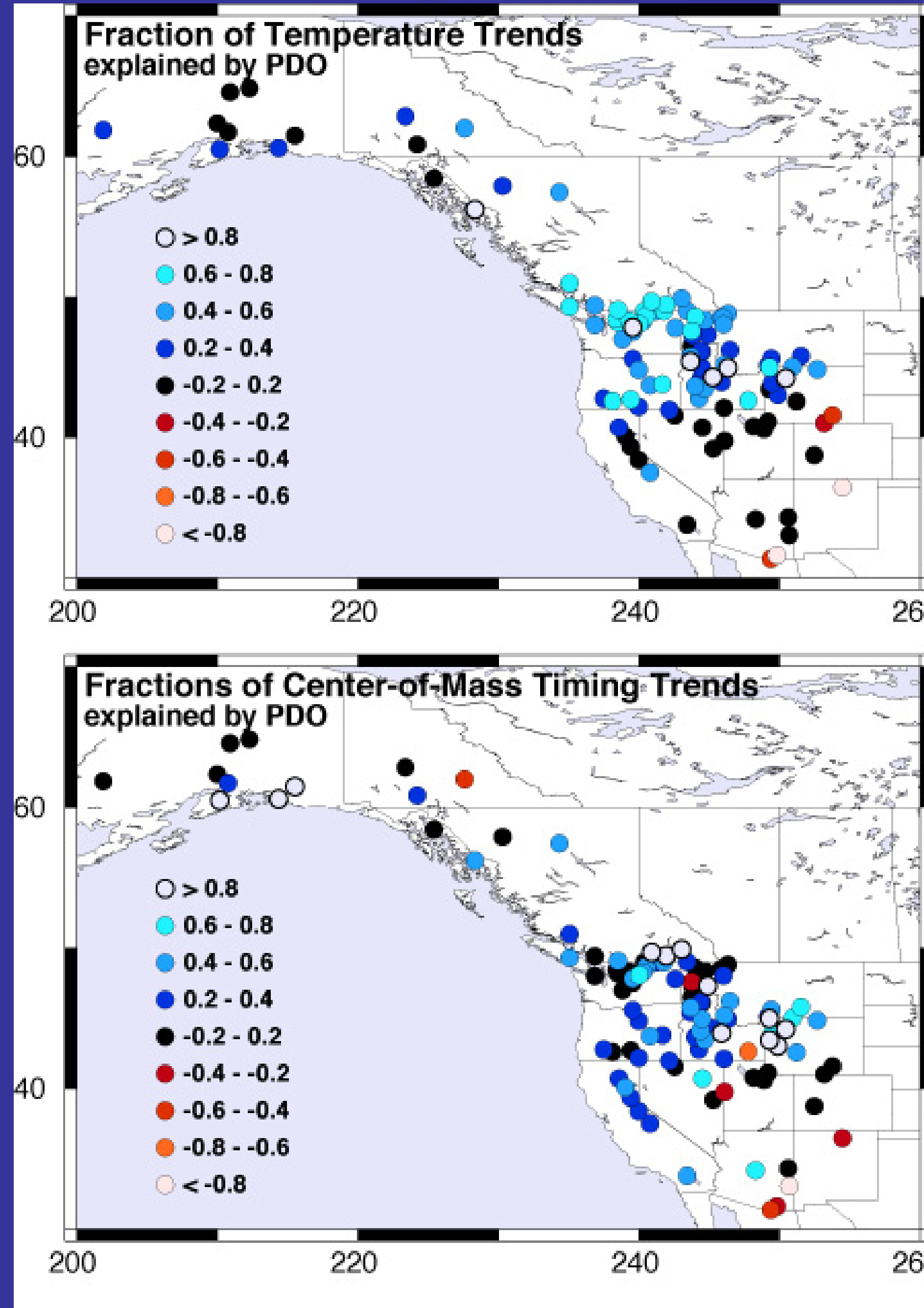




Regression models--relating year-to-year fluctuations of temperature and streamflow-timing to the PDO before or after the 1976-77 step change--indicate that most of the observed trends are not explained by the PDO step alone.

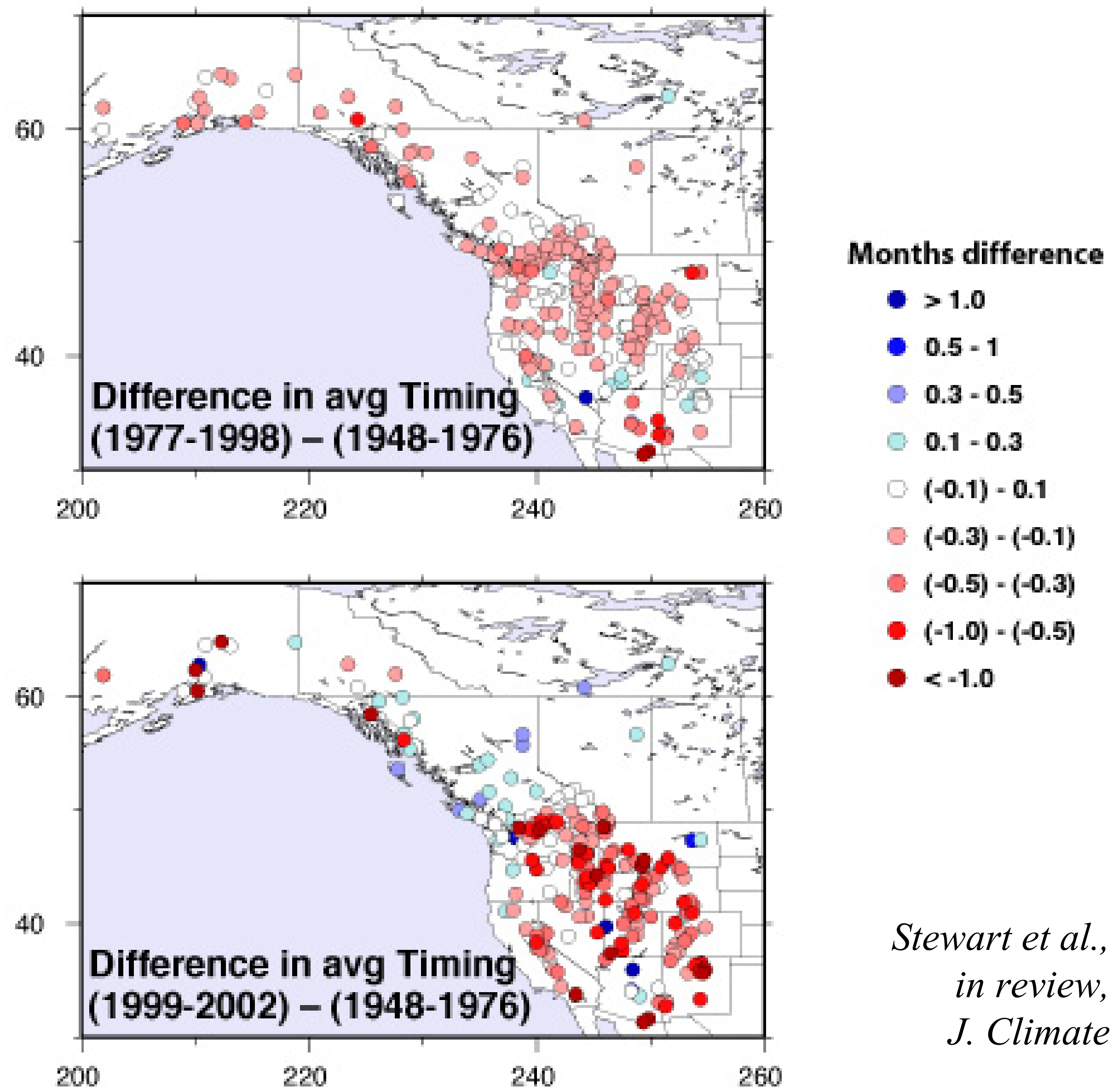
Dark colors in this diagram indicate that LESS of the trends are attributable to PDO.

Stewart et al., in review, J. Climate



The recent reversal of PDO has NOT slowed the progress of timing trends.

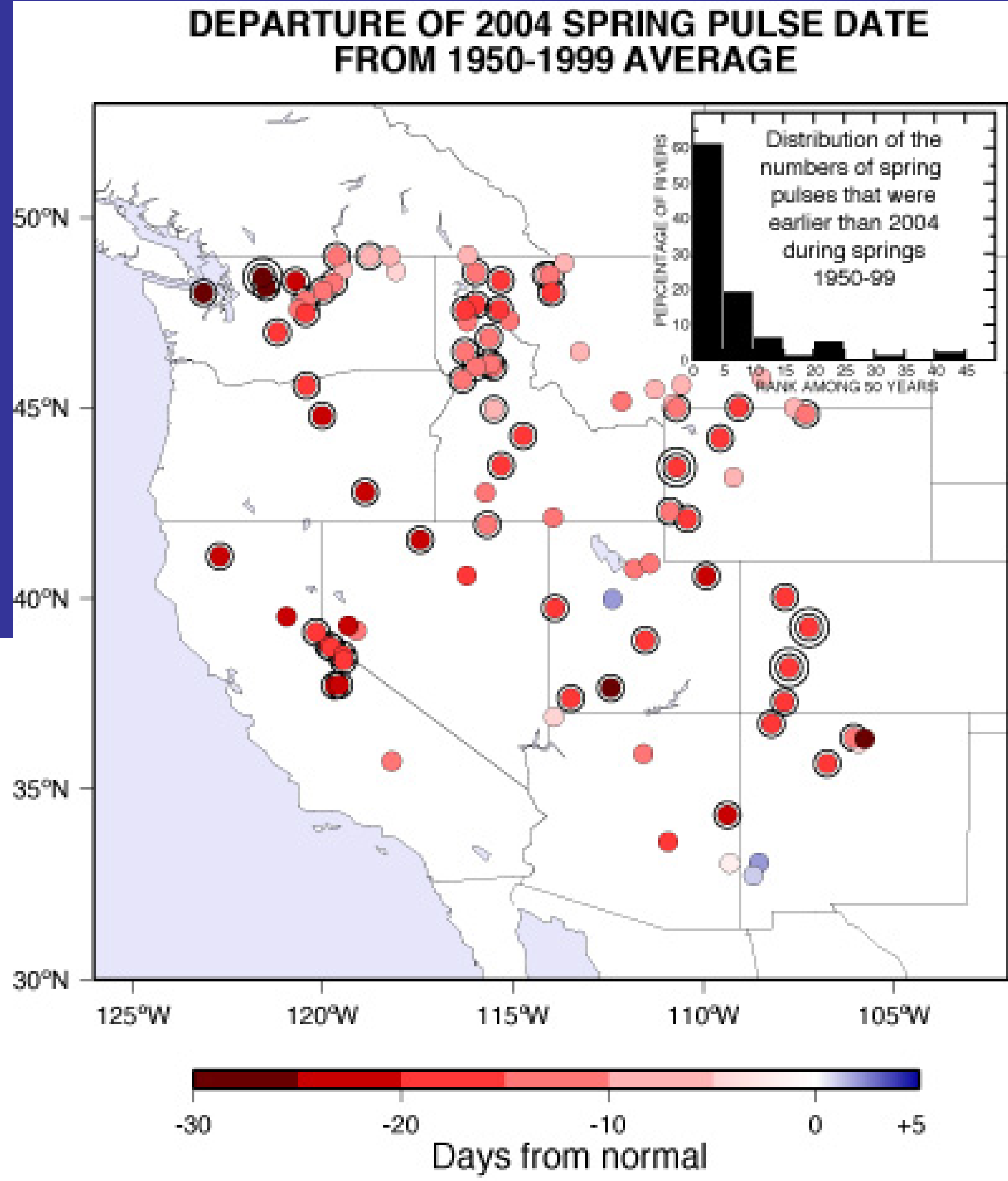
The average streamflow timing in the years after the 1998 transition to a “La Nina-like” PDO state have been even earlier than timings in the preceding “El Nino-like” PDO epoch.

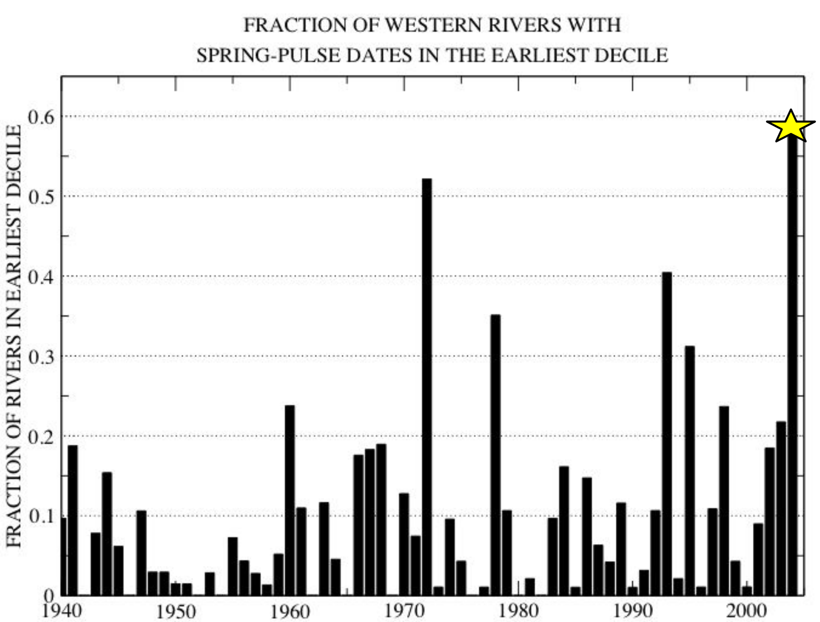


Stewart et al., in review, J. Climate

Spring 2004 has been particularly early!

Rivers across the West began their snowmelt 10 to 30 days earlier than usual.

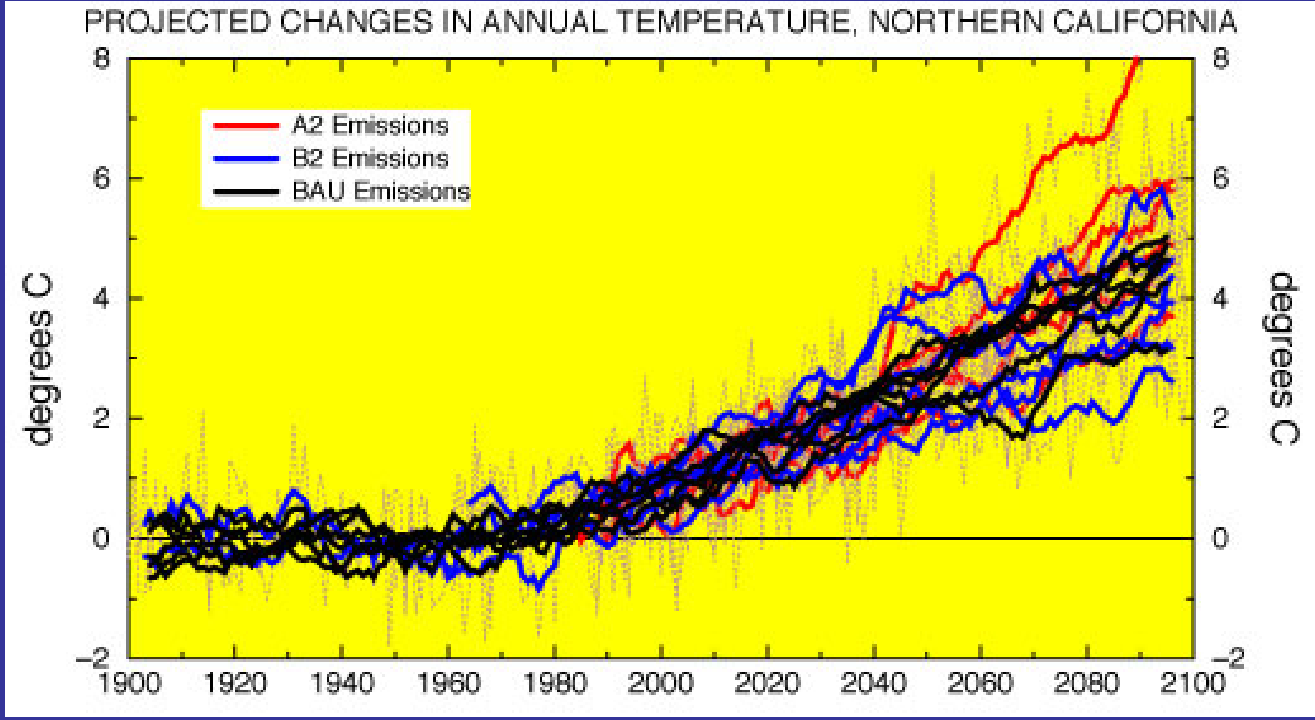


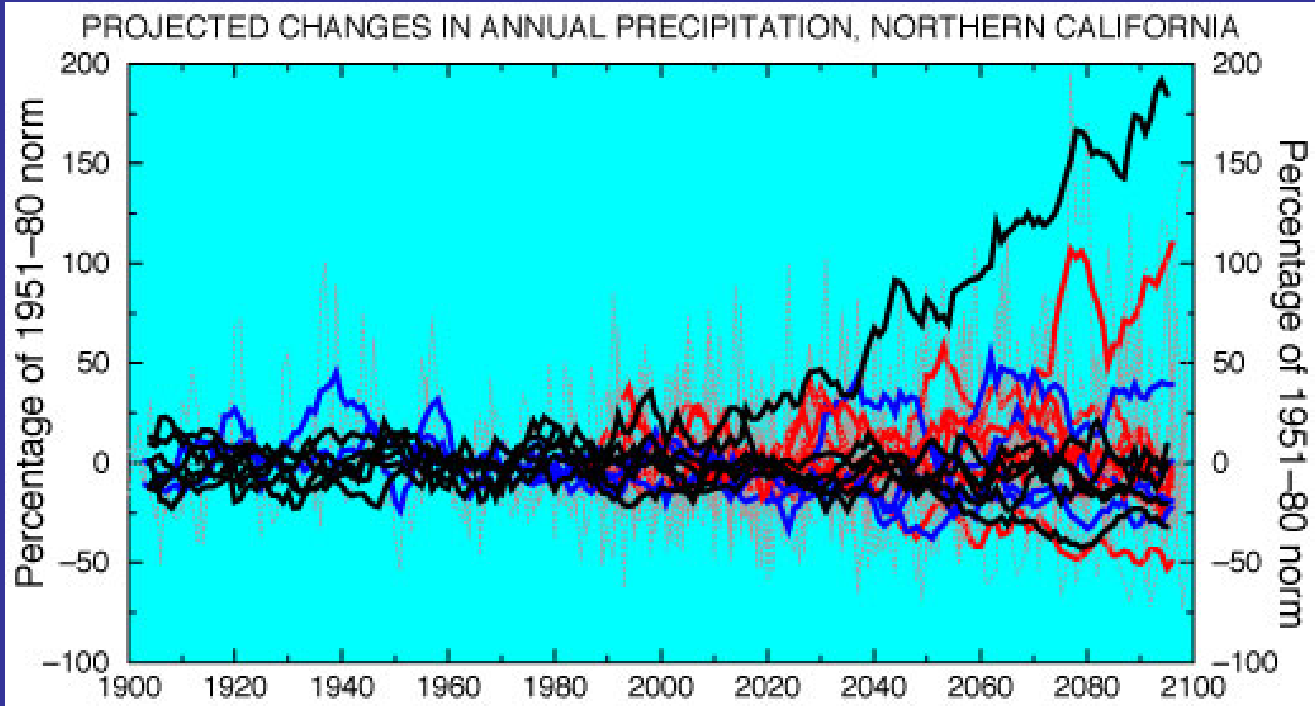


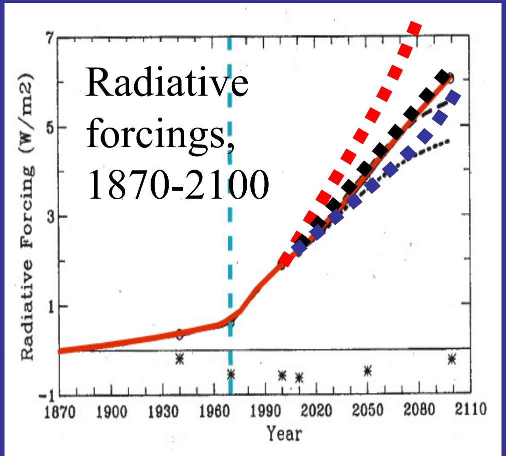
Spring 2004 was nearly record breaking in more rivers than in any spring in the past 60+ years.

Under projected greenhouse forcings,

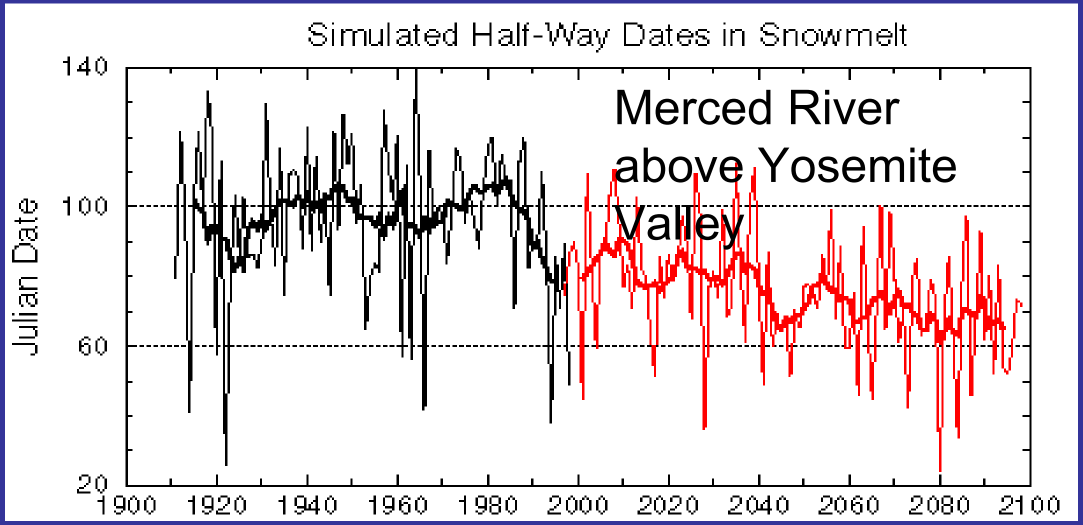
climate models yield a narrow range of warming scenarios and (amidst a broader overall range) a tendency for little precipitation change in California.



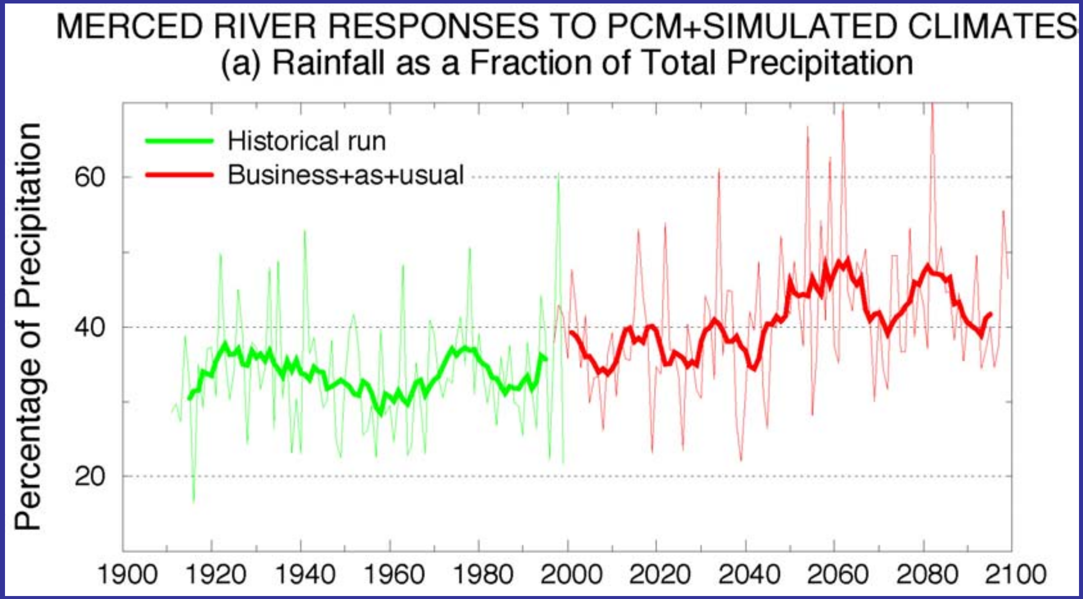




Even the coolest of these projected warmings will yield significantly earlier snowmelt…

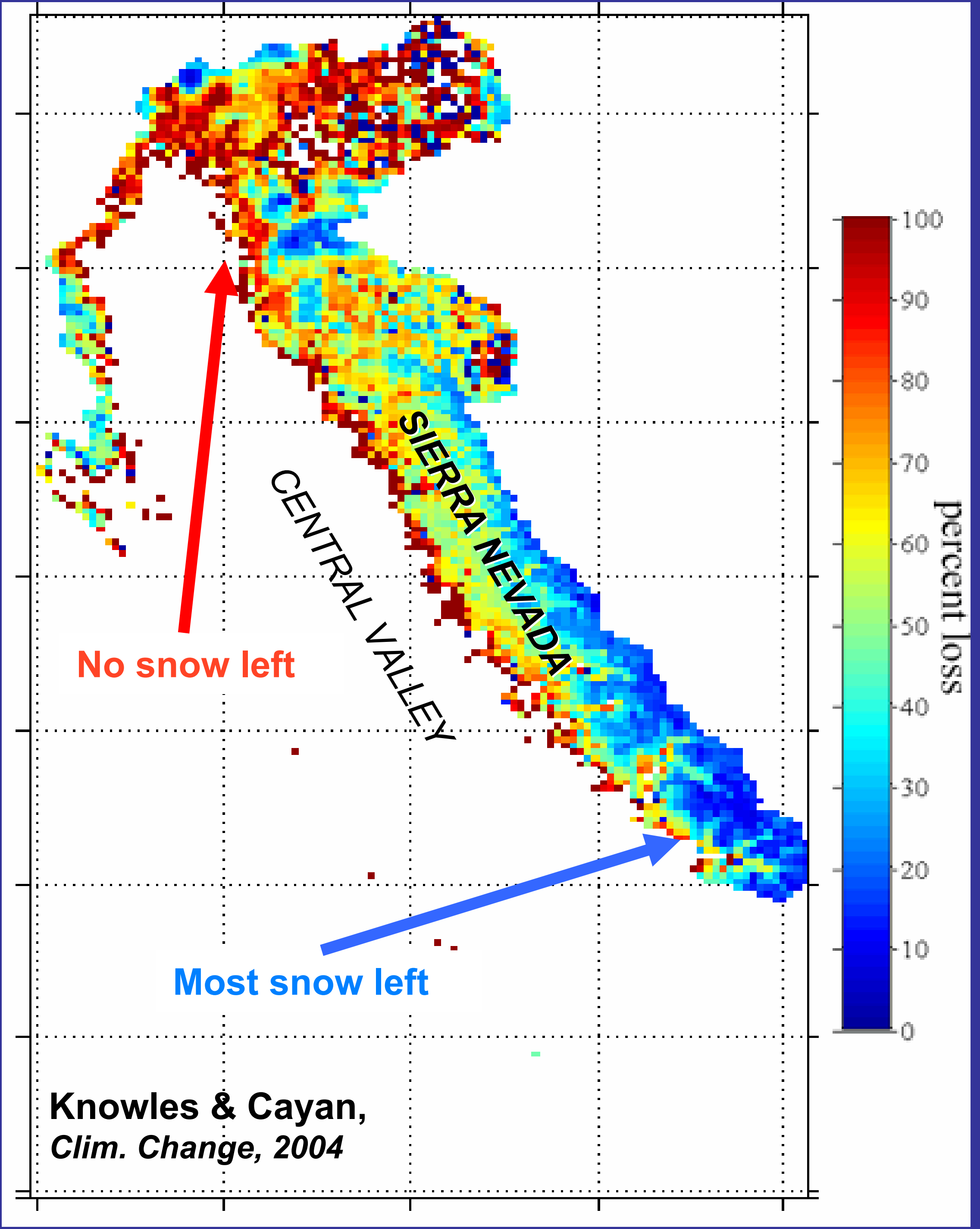


..and a greater fraction of precipitation as rain.



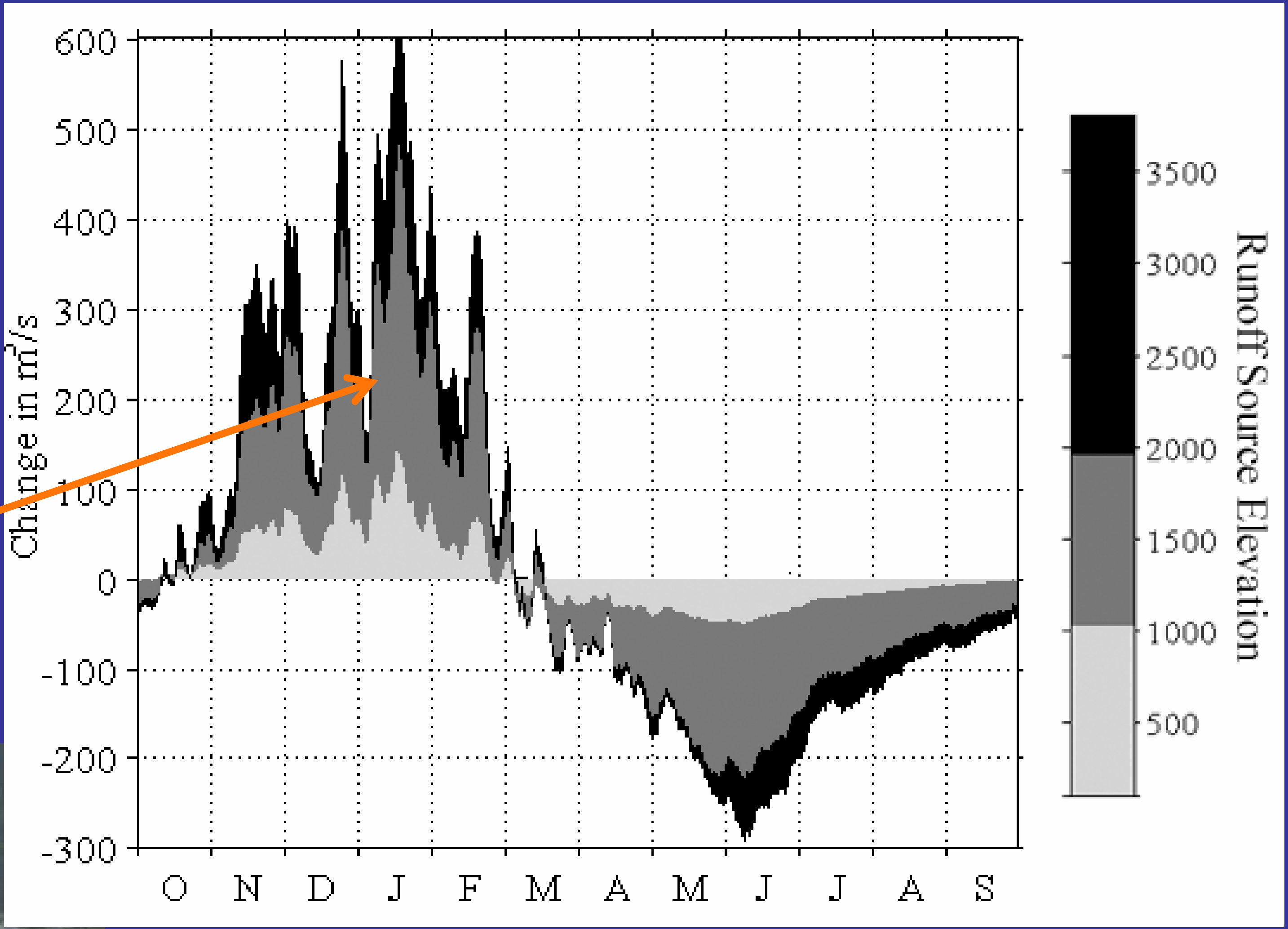
Dettinger et al., 2004

By the middle of the 21st Century, *even in one of the coolest scenarios*, earlier snowmelts & major reductions in snowpacks of the Sierra Nevada are projected...



Changes in Freshwater Inflow to SF Bay, 2060 – 2000

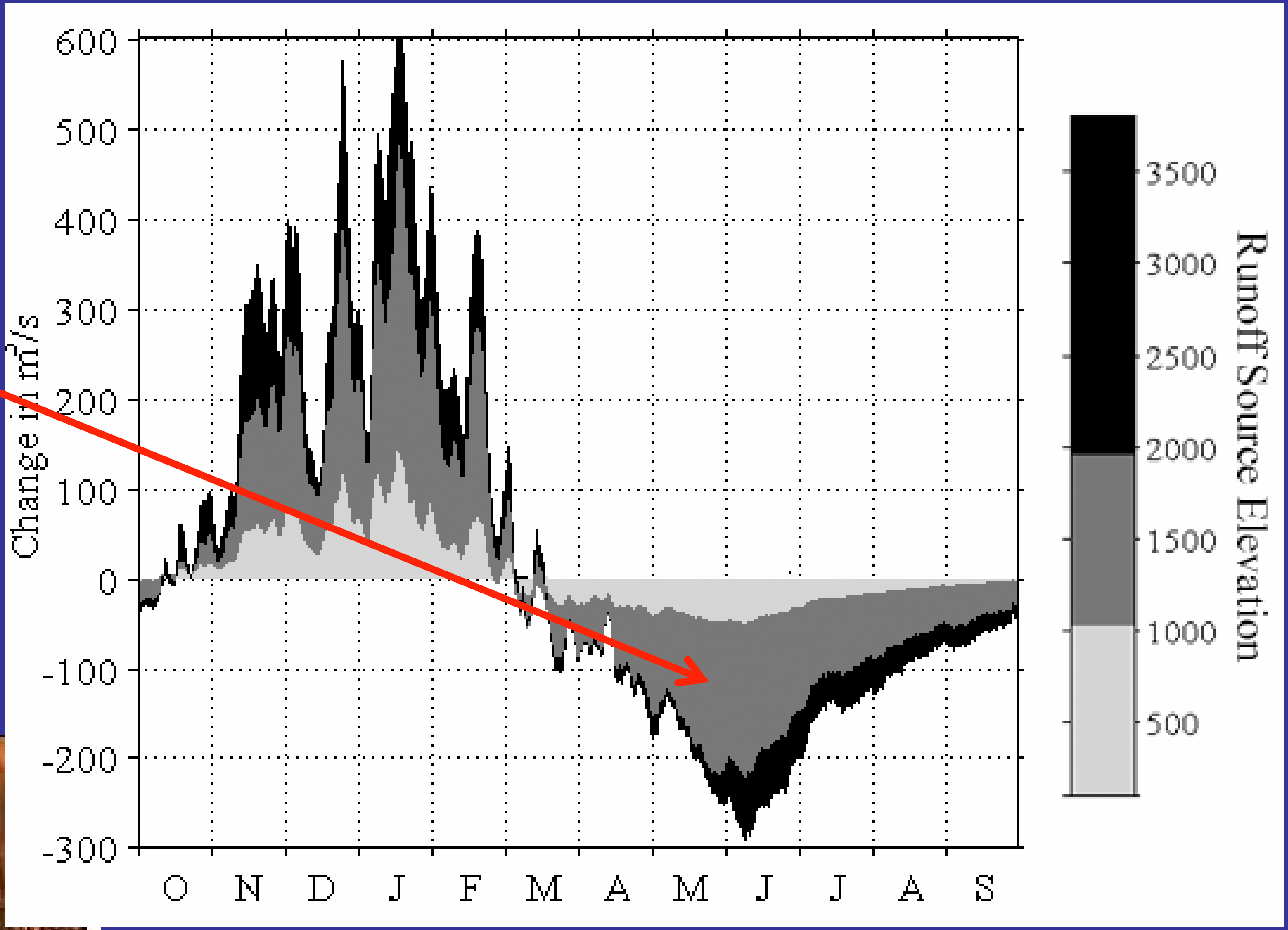
Even with no change in precipitation, the coolest of these temperature projections will bring **more severe winter floods**…



Knowles and Cayan, 2004; http://www.cgd.ucar.edu/cas/ACACIA/workshops/precip/dettinger.pdf

Changes in Freshwater Inflow to SF Bay, 2060 – 2000

… and much drier springs and summers.



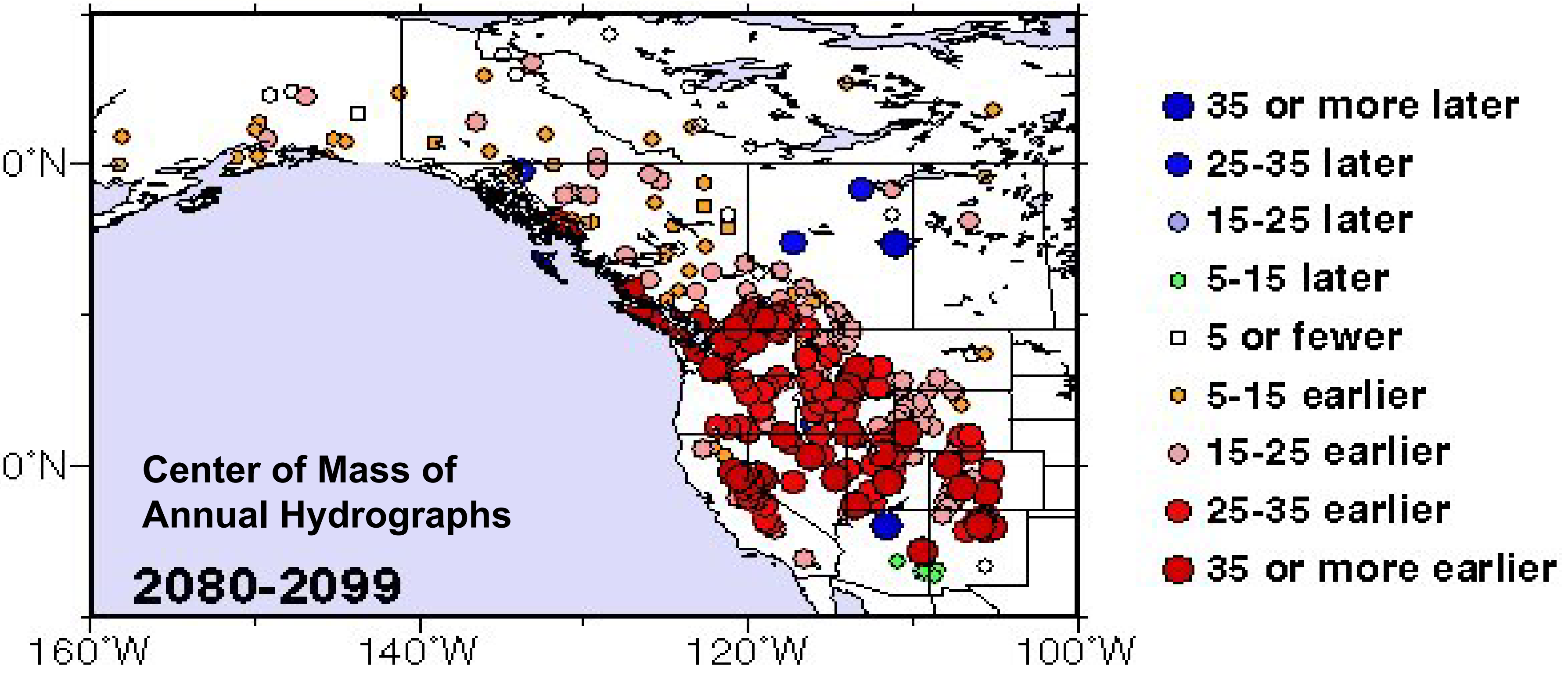

Sequoia NP, July 2000

Knowles and Cayan, 2004

Dettinger et al., 2004

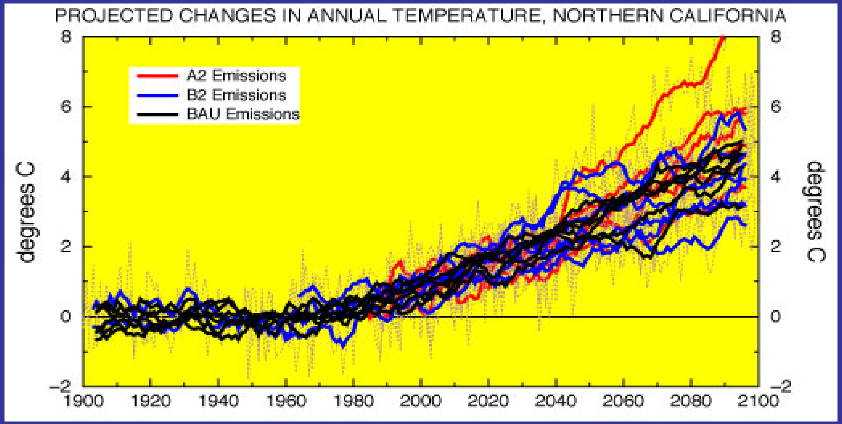
Trends toward earlier snowmelt runoff are projected throughout the West,…

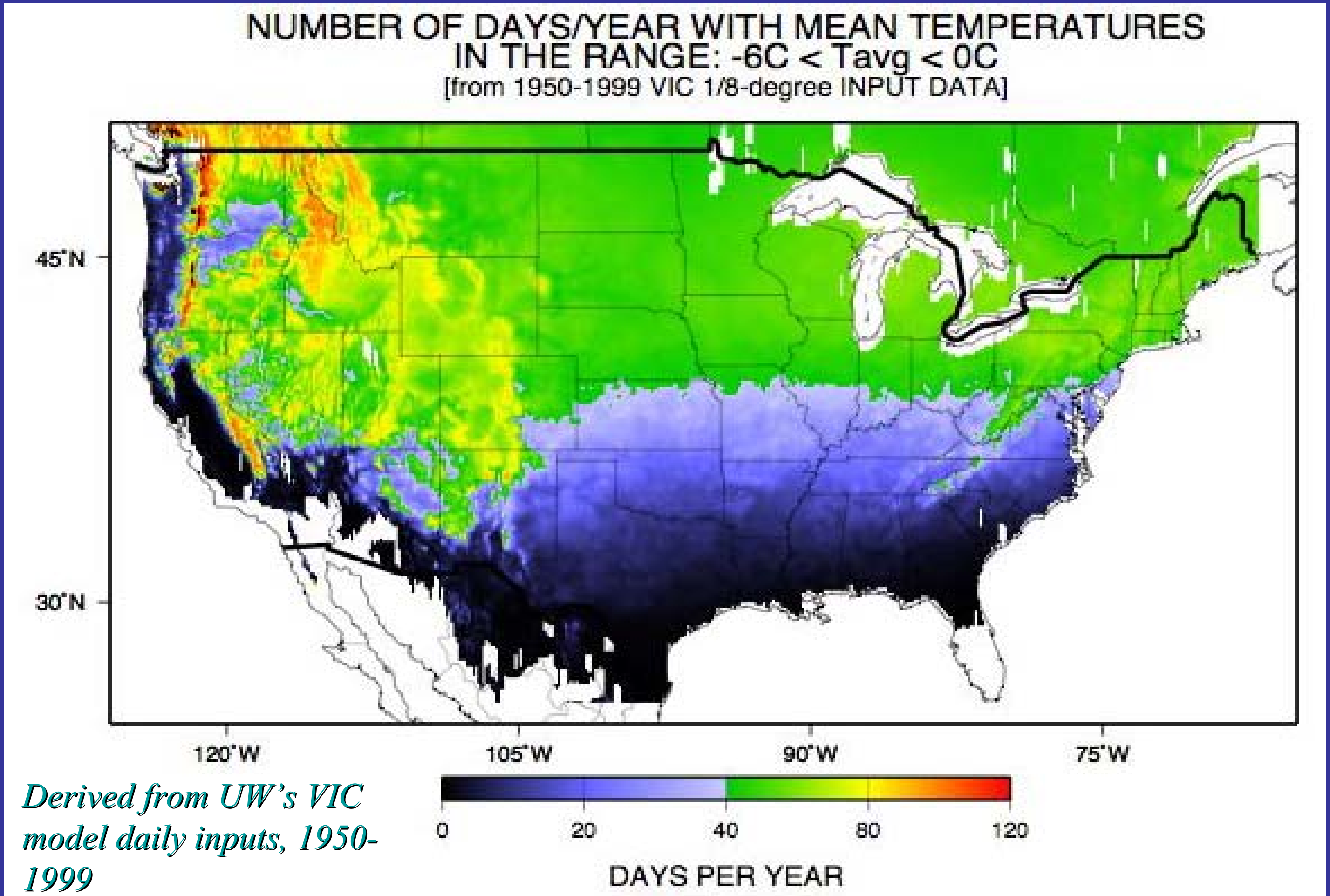
Projected streamflow timings, 2080-99 vs 1951-80



Iris Stewart et al., 2004

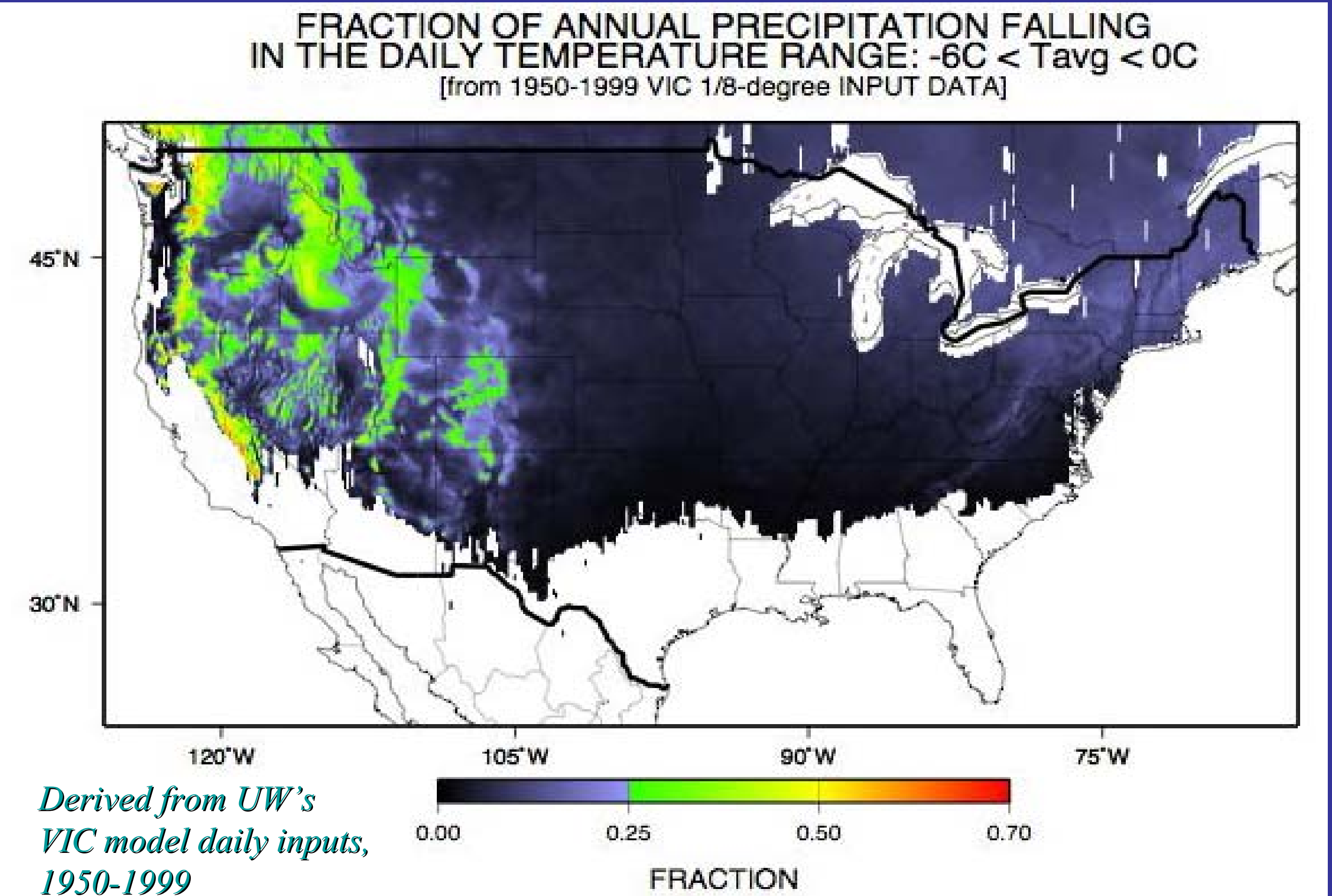
ESTIMATING INFLUENCES OF PROJECTED WARMINGS ON SNOW-SEASON LENGTH



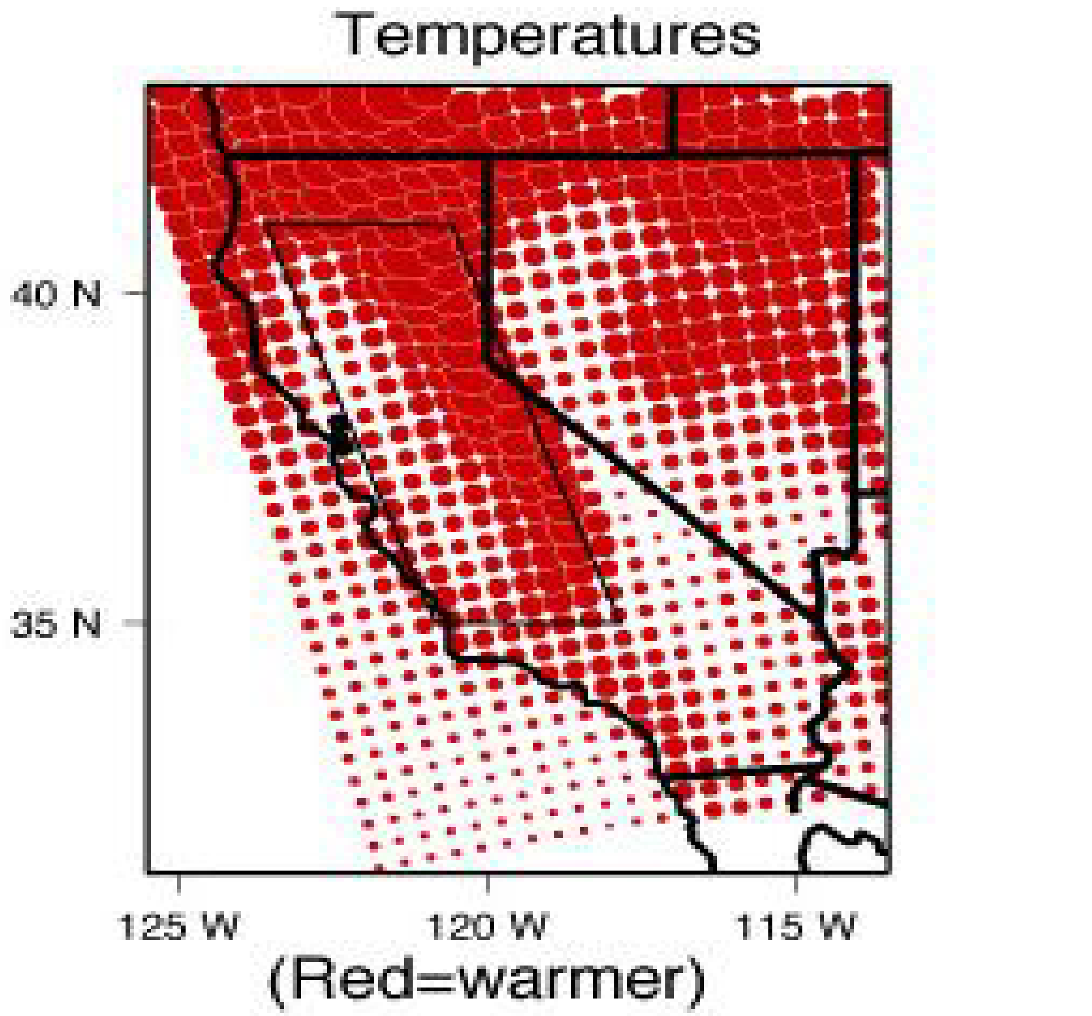


Derived from UW's VIC model daily inputs, 1950-1999

ESTIMATING INFLUENCES OF PROJECTED WARMINGS ON SNOW vs RAIN

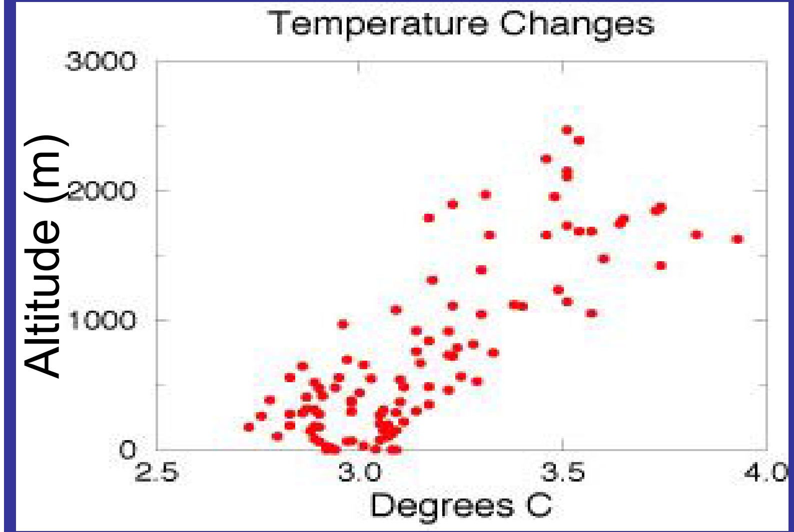


Derived from UW's VIC model daily inputs, 1950-1999



MM5 Regional-Climate Model output driven by Parallel Climate Model simulations, by Ruby Leung, PNNL. 2001

…and high altitudes may get even more of the warming!



NOTE: See Snyder et al (UCSC), 2002, GRL, or various recent efforts by Miller (UCB) and/or Kim (UCLA), for more discussions of this effect.

USGS

FINDINGS

- Rivers across the West are yielding earlier snowmelt runoffs (by an average of about 9 days) in recent decades.
- Spring (and winter) warming trends have driven these timing trends, and also have caused earlier green-up of western plants.
- Natural climate variations (e.g., PDO) have contributed, but other forces are also at work.
- Western rivers may be flowing 20 – 30 days earlier by the end of the 21st Century, and California is especially vulnerable (and thus may feel the impacts even sooner).

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